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Determining how risk effects predator-prey interactions of marine communities in the nearshore environment of South Bimini, The Bahamas

Kendall Brancart
Nova Southeastern University, kb1899@mynsu.nova.edu

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Kendall Brancart

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Approved:
Thesis Committee

Major Professor: Dr. Derek Burkholder

Committee Member: Dr. David Kerstetter

Committee Member: Dr. Mark Bond

HALMOS COLLEGE OF NATURAL SCIENCES AND OCEANOGRAPHY

DETERMINING HOW RISK EFFECTS PREDATOR-PREY INTERACTIONS OF MARINE COMMUNITIES IN THE NEARSHORE ENVIRONMENT OF SOUTH BIMINI, THE BAHAMAS

By

Kendall Brancart

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Outline

Abstract

Predators often have strong top-down effects on ecosystems and are considered a priority for conservation and management. Predator activity can influence prey distribution, abundance, and foraging behaviors and are likely to influence habitat by impacting ecological and environmental characteristics as well as presence of competitor species. There are knowledge gaps of the functional diversity of fish assemblages, non-consumptive predator effects, and environmental effects on fish assemblages. With this study, effects of top marine predators, such as sharks and great barracuda, on diversity and abundance of prey communities were examined in putative low (north side of South Bimini = lagoon) and high-risk (south side of South Bimini = flat) areas around South Bimini, The Bahamas. Baited remote underwater video surveys (BRUVs) deployed in the nearshore habitat captured abundance and potential predator-prey interactions. Predator and prey abundances at each site were compared to determine potential risk affect within high and low risk environments. A general baseline of predator and prey species was established throughout six months of observation (January- June 2018). Results showed a difference in prey communities between high and low risk habitats. Teleost abundance was highest on the south side of South Bimini. There were no differences in flight behavior of prey from predator (sharks vs barracuda). Longitude, depth, temperature, salinity, and dissolved oxygen were significantly linked to biotic assemblages. The identification of significant factors influencing predator-prey interaction is important in understanding community composition and for future implementation of conservation and management practices pertaining to nearby mangrove and seagrass habitats.

Key Words: Top-down effect, predator, prey, risk, abundance, diversity, predator-prey interaction, Baited remote underwater video surveys (BRUVs)

Introduction

Understanding inter-species interactions in a predator prey context and how these may differ between habitats is important to implementing effective ecosystem management from both a fisheries and conservation perspective. Ecological information pertaining to the diversity, distribution, and abundance of sharks and teleosts is vital in developing these strategies. Predator and mesopredator communities exert top-down pressure on prey species, which can impact community dynamics by altering habitat utilization, foraging behavior, energetic demands, and competition (Heupel et al. 2014; Schlaff et al. 2014). Risk of predation can help determine prey distribution, abundance, and foraging habits.

Areas with active marine protected areas (MPAs) provide relatively undisturbed conditions (e.g., reduced fishing pressure, managed resources, protected habitat) for scientists to examine predator-prey dynamics and their environmental influence. North Bimini Marine Reserve (NBMR) was proposed by the government of the Bahamas in January 2000 (Marine Conservation Institute 2019; Jennings et al. 2012). Marine protected areas are established to restrict human activity for conservation purposes, to protect natural and cultural resources, protect ecosystems, and sustain fisheries populations. There are many forms of MPAs, including marine sanctuaries, estuarine research reserves, ocean parks, and marine wildlife refuges. Conservation of biodiversity and ecosystem service maintenance are the main objectives of MPAs (Colton and Swearer 2010; Jennings et al. 2012; Ward-Paige 2017). An important component of MPAs are designated “no take” zones, which have proven to be a valuable tool in the management of marine resources by establishing undisturbed habitat, making the protected ecosystem more assessable from a baseline perspective (Babcock et al. 1999; Wise 2014). Effective MPAs are important spatial mechanisms for conservation and resource management, and can provide an efficient representation of biodiversity within “no-take” sanctuaries (Wise 2014; Malcolm et al. 2016). In Bimini, the proposed NBMR from 2000 is designed to safeguard sport-fishing and tourism in the area and is established as a no-take zone that states no fishery product can be harvested and no disruptions to the marine environment can occur without special permissions (Bounds 1978; Malcolm et al. 2016). An increasing implementation of no-take zones within MPA

spatial planning has highlighted the need for better non-invasive survey methods to monitor change, especially for areas or depth regions that are problematic for divers to survey (Hannah et al. 2014). In 2009, the NBMR was officially declared during a widely publicized Town Meeting by the Bahamas Environment, Science, and Technology Commission (BEST Commission) (Woon 2015). It has not been fully implemented and formalized by the Government of the Bahamas (Wise 2014; Woon 2015; Marine Conservation Institute 2019). However, shark fishing in all of The Bahamas has been prohibited since 2011 after an amendment was made to the Fisheries Resources Act, making the Bahamas a shark sanctuary (Haas et al. 2017). This act is designed to protect all shark species by banning commercial shark fishing, imports, and exports. More recently, a Marine Protection Plan was created by members of the Bahamas Protected project team, an initiative to support the government's commitment to manage and expand MPAs in the Bahamas, to protect 20% of the country's seabed by 2020 (Bahamas Protected 2018). This plan has been submitted to the Government of The Bahamas to expand current MPAs in the Bahamas in order to protect future jobs, the environment, and the Bahamas natural resources and food (Bahamas Protected 2018).

One of the functions of the proposed marine reserve is to protect the remaining mangrove wetlands in Bimini, which serves as the only mangrove habitat on the western edge of the Grand Bahamas Bank and is crucial to tourism and fisheries health (Woon 2015). Mangrove habitat is defined by the presence of prop-roots and pneumatophores (aerial root specialized for gaseous exchange) with overhanging branches in the intertidal zone (the shallow zone along the coast between land and sea) limited to tropical and subtropical regions (Laegdsraard and Johnson 2001; Nagelkerken et al. 2008). Mangroves are characterized by climate (e.g. temperate, tropical), sedimentation (e.g. fine sand, mud), and tidal currents (e.g. intertidal) (Nagelkerken et al. 2008). Tropical and subtropical mangroves are recognized worldwide as important nursery habitat for juvenile fish and invertebrates due to the structural complexity of mangrove prop-roots (Laegdsraard and Johnson 2001; Whitfield 2017). Mangroves cycle nutrients (Boyer et al. 2004), provide protection from predators (Nagelkerken et al. 2008), and exhibit high productivity (Sheridan and Hayes 2003; Granek et al. 2009). Mangroves that fringe shallow shorelines, as in Bimini, provide important intertidal and subtidal nursery

habitats due to their intricate prop-root systems maximizing resource availability and minimizing predation risk (provide refuge) (Thayer et al. 1987; Robertson and Duke 1987; Robertson and Duke 1990; Laegdsgaard and Johnson 2001; Trave and Sheaves 2014, Stump et al. 2017). The Bahamas lack quantitative data on faunal communities and their role and use of mangrove communities (Newman et al.2007). Understanding the value of mangrove habitat during all potential life stages of teleost species and sharks is important for their conservation and management.

Seagrass meadows are also recognized as important habitats for fish and invertebrates and play a fundamental role in maintaining local biodiversity (Newman et al. 2007; Trave and Sheaves 2014). Seagrass evolved from a single lineage of flowering plants (monocotyledonous) that have adapted to exist submerged in the ocean (Orth et al. 2006). Contrastingly, other marine plant groups such as salt marsh plants, mangroves, and marine algae are descended from multiple diverse evolutionary lineages (Orth et al. 2006). Seagrass beds are found in shallow coastal areas and are characterized by vegetation, buried root and stem under substrate, flowers and seeds, and dense leaves (Duarte et al. 2010; Kholis et al. 2017). Seagrass meadows have colonized all but the most polar seas and are a good area for sheltering, spawning, and foraging for many fish and invertebrate species (Orth et al. 2006; Kholis et al. 2017). Like mangroves, seagrasses serve as a nursery ground for juvenile organisms (Orth et al. 2006; Whitfield et al. 2017). There are conflicting studies that discuss seagrass habitats having high diversity of teleost species (Newman et al. 2007; Kholis et al. 2017) and having low species diversity (Orth et al. 2006). Seagrasses in coastal waters are directly in the path of watershed nutrients (e.g. carbon, nitrogen, phosphorous) through precipitation and runoff, unlike mangrove forests which are largely unaffected by water quality (Orth et al 2006). Newman et al (2007) concluded that mangrove fish and invertebrate community biomass, abundance, and diversity decreased during the night with a subsequent increase of these communities in seagrass meadows. Seagrass habitat has high primary production (from seagrass blades, algae, and phytoplankton) and exhibit varying degrees of complexity in small areas (Heck and Wetstone 1977; Klumpp et al. 1993; Granek et al. 2009; Duarte et al. 2010). Seagrasses act as ecological engineers, influencing physical, chemical, and biological environments by altering water flow, nutrient cycling, and food web structure

(Orth et al. 2006). Seagrasses provide a source of carbon to the detrital environment. The carbon is transported to the deep sea, providing organic matter to food-limited environments (Orth et al. 2006; Duarte et al. 2010). Rhizomes (continuously growing horizontal underground stem), seagrass leaves, and roots modify currents and waves, trap and store sediments and nutrients, and filter nutrient inputs to the coastal ocean (Suchanek et al. 1985; Orth et al. 2006). Losses of seagrass meadows have occurred due to nutrient and sediment runoff, hydrological alterations (e.g. water diversion, exploitation of groudwater aquifers), and commercial fishing practices (Orth et al. 2006; Rosenberg et al. 2000). Risk analysis and forecasts of anthropogenic and climate stresses can inform conservation and management strategies for the preservation and enhancement of seagrass meadows.

In this study, I examined the composition and predator and prey relative abundance using baited remote underwater video surveys (BRUVs) to passively record species composition and abundance, and predator-prey interactions in the presence of bait. This is a continuation of a multi-year study that classifies species dynamics and diversity around the island of Bimini. Predator communities of sharks and great barracuda were examined to understand how they impact prey community dynamics in areas of low and high risk of predation. Risk was established from species observations in previous studies located in Bimini (high risk: south side of South Bimini; low risk: north side of South Bimini). Bimini is situated on the western edge of the Grand Bahama Banks and the eastern edge of the Gulf Stream (Hansell et al. 2018). The northern side of south Bimini is characterized as a semi-enclosed shallow flat bordered by mangroves and is exposed to the Grand Bahama Bank to the east and a channel opening to the south. The southern side of South Bimini is exposed to the Gulf Stream to the west and lie adjacent to the shallow flats of South Bimini (Hansell et al. 2018). The southern end of South Bimini is also exposed to the Grand Bahama Bank to the east. The positions of the north and south side of South Bimini suggest that there could be a higher influx of species, nutrients, and food on the south side due to the semi-enclosed habitat of the north side. This strategic position to the Gulf Stream and Grand Bahama Bank has resulted in a diverse array of marine habitats from seagrass meadows, mangroves, coral reefs, sand flats, and rock substrates (Burke 2015).

Common shark species in the Bahamas that are known to frequent our study site and comparable habitats are: lemon (*Negaprion brevirostris*) sharks, tiger (*Galeocerdo cuvier*) sharks, Caribbean reef (*Carcharhinus perezi*) sharks, blacktip (*Carcharhinus limbatus*) sharks, blacknose (*Carcharhinus acronotus*) sharks, bull (*Carcharhinus leucus*) sharks, great hammerheads (*Sphyrna mokarran*), and nurse (*Ginglymostoma cirratum*) sharks. This study provides an assessment of predator and prey communities across different habitats and environmental factors. Top predators (e.g., sharks and barracuda) are likely to influence habitat through resource exploitation, adaptations to changes in salinity, habitat preference, interspecies competition, and abundance and distribution of prey and other resources (Knip et al. 2010). Environmental parameters such as temperature, salinity, and dissolved oxygen, are important factors that may impact predator and prey species in nearshore environments (Trave and Sheaves 2014). Species-level responses to these factors are important given the rapidly changing environment and the changing environment's impacts on marine biodiversity (Schlaff et al. 2014). Major shifts in these conditions could lead to ecosystem alteration, loss in biodiversity, and loss of marine resources. Understanding these environmental parameters and how they impact Bahamian ecosystems will help determine their status in the Bahamas and create a baseline to which future changes to the environment can be judged.

Predator-Prey interactions

There are a growing number of studies that focus on prey ability to discriminate between different predators and prey exhibiting predator-specific responses. Predator-prey interactions in aquatic biology have been intensively studied in the past several decades, mainly focusing on predator behavior (Wetzel and Liken 1991). Predator-prey interactions play a fundamental role in community dynamics influencing both the behavior and population biology for most taxa. Predator avoidance decisions vary depending on the characteristics of predator, prey, and the physical environment (Guttridge et al. 2012; Catano et al. 2017). Risk can be determined by the abundance of predators in the habitat and the intrinsic risk of the habitat. Intrinsic habitat risk is determined by the habitat characteristics that influence the probability of predator-prey interaction (non-consumptive) or death during an encounter (Heithaus and Dill 2006).

The risk that prey will tolerate often depends on the physical environment, predator attributes, and prey conditions. These factors include habitat cover, substrate color, light availability, water depth, turbidity, predator hunting mode, and prey hunger state (Carrier et al. 2004; Nagelkerken et al. 2008; Catano et al. 2017). Fish are also known to control other organisms through predation, acting as ecosystem engineers, and are able to mediate nutrient fluxes (Villéger et al. 2017). Species exhibit a large range of trophic strategies from herbivory to piscivory, including various levels of omnivory, planktivory, and detritivory (Villéger et al. 2017). Foragers must often balance conflicting needs (e.g., obtaining food and avoiding predation) as the highest risk zones are often the most profitable (e.g., best food source) (Laegdsgaard and Johnson 2001). In the Florida Keys, herbivorous fish exhibited threat-sensitive responses by decreasing their foraging near models of great barracuda and black grouper anchored to the seafloor (Catano et al 2017). The spatial effect of barracuda and grouper on bite rates were similar, with herbivore bite rates increasing with increased distance from the models (Catano et al. 2017). Barracuda suppressed herbivory by 50% at mid-day and dusk compared to dawn (Catano et al. 2017). These results stem from non-consumptive predation risk effects and the sit-and-pursue predation behavior of barracuda more than time of day. In shark Bay, Australia, cormorants are known to modify their habitat use at multiple spatial scales to avoid predation from tiger sharks (Heithaus et al. 2009). Dugongs, dolphins, and cormorants will avoid prey-rich areas when tiger sharks are present and opt for safer habitat (Heithaus et al 2009). Lima and Dill (1990) had proposed habitat use decisions were based on a combination of prey abundance and predation risk. Prey response to predators are based on habitat coverage, resource availability, and predator abundance (Stump et al. 2017).

Prey are more likely to engage in energetically expensive avoidance behaviors for large predators that pose a greater threat (Catano et al. 2017). Conversely, prey are more willing to trade food for safety when their hunger (i.e., possibility of starvation) outweighs their want for safety. Prey exhibit this ‘reward versus safety' trade-off more when predators have a wider “zone of fear”, the area in which a predator has potential risk effect on prey (Catano et al. 2017). Predation risk alters both behavior of prey and

the consumption of primary producers (Catano et al. 2017). It is also possible that more threatening predators have a greater impact on prey communities.

Apex predators, such as sharks and barracuda, often have strong top-down effects on ecosystem components and are considered a priority for conservation and management (Frisch et al. 2016). The top-down control predators exert on prey species can significantly alter community structure. There is still a limitation in understanding the dynamics of predators in regulating prey populations (Kitchell et a. 2002; Heupel et al. 2014; Frisch et al. 2016; Roff et al. 2016b). Sharks hold an important role on coral reefs but some studies suggest that they play a small role in trophic cascades (Roff et al. 2016b). Other studies indicate that sharks can play a significant role in top-down control of ecosystems (Myers et al. 2007; Burkholder et al. 2013; Roff et al. 2016a). Sharks can exert risk behavior effects that can influence lower trophic levels by disrupting their foraging activity and habitat use, but herbivores will exhibit similar behavioral responses to large predatory fish as well (Roff et al. 2016b). However, risk of predation is recognized as a key ecological and evolutionary processes in many studies. Interactions can change over time as predators mature and go through ontogenetic changes (shifts in diet and behavior as an animal matures) (Sundström et al. 2001; Motta and Wilga 2001; Robbins and Renaud 2016). Relyea (2003) determined prey can discriminate between different predators and exhibit predator-specific interactions. Predators induce a wide range of behavioral, morphological, and physiological responses in their prey. It is possible that there will be a difference in risk behavior when faced with barracudas (sit-and-pursue hunters) versus sharks (active, coursing hunters) (Catano et al. 2017). There are also few studies of how anti-predator responses in prey vary with predator identity and time of day. Two separate studies found that the abundance and distribution of tiger sharks throughout the species' range in Western Australia are likely influenced by the availability of locally important prey (Heithaus et al. 2002; Wirsing et al. 2007; Burkholder et al. 2013). Biotic factors such as prey density, availability, and predator avoidance play a role in the spatial ecology and populations of sharks and other species (Heithaus and Dill 2006; Schlaff et al. 2014). Movement of several predators were found to be linked to prey abundance and availability. Temperature, salinity, dissolved oxygen levels, and tide state can also influence predator abundance and movement (Abrahams et

al. 2007; Schlaff et al. 2014; Coffey and Holland 2015), making it difficult to tease these drivers apart.

Prey become more vigilant or leave high food habitats as sharks spend more time there, increasing predation risk (Heithaus et al. 2002). Heithaus et al. (2002) also found that dolphin populations were concentrated around seagrass bank edges when sharks were present to avoid predation, rather than being evenly distributed across the shallow habitat. Many foragers must select between foraging in food-rich habitats that are more dangerous and habitats that are safer but have lower prey abundance (Heithaus 2005; Heithaus and Dill 2006). Risks can be divided into categories of probability of encounter and natural habitat risk. Spatial variation in predator encounter rates and natural habitat risk influences the likelihood of predator and prey distributions being linked at multiple spatial scales in a complex system of predator prey interactions.

Protective Habitat

Mangrove habitats are essential for the growth and development of many marine fishes and are useful to many smaller species, reducing the probability of encountering large predatory species (Newman et al. 2007; Hylkema et al. 2015). Laegdsgaard and Johnson (2001) found that species richness and abundance of juvenile fish were higher in the mangroves than they were in seagrass habitat, even though refuge value was equal in both habitat types. The structure of mangroves also allows smaller fish to have increased food accessibility. In a contrasting study, many Caribbean fish in a mangrove-seagrass-reef system consumed little or no food from the mangrove habitat even when mangrove roots were permanently submerged throughout tide cycles (Nagelkerken et al. 2008). Caribbean island mangroves are characterized by narrow fringes providing substantial shelter but little food availability. Nagelkerken et al. (2008) further concludes that fish utilizing mangroves throughout the day migrate to seagrass beds at night in order to feed. In turn, species utilizing seagrass beds during the day for shelter remain in seagrass habitat for feeding.

There are inconsistencies within studies (Beck et al. 2001; Sheridan and Hays 2003; Newman et al. 2007; Nagelkerken et al. 2008; Hylkema et al. 2015), which make it difficult to determine the importance of how mangroves function as nurseries, and their

contribution to the overall life history of vertebrates and invertebrates. While mangroves are important habitat that provide an increased food density for animal growth, tide-dependent and turbid waters reduce the effectiveness of predation, and complex root systems to reduce predator efficiency, there is evidence that other habitats may have similar functions on species composition (Beck et al. 2001; Sheridan and Hays 2003). Mangroves and other intertidal habitat as effective nurseries require more experimental verification through comparing growth and survival of species in mangroves to adjacent habitat type (seagrass, coral reef, non-vegetative flats) and the process of movement from juvenile to adult habitat (Sheridan and Hays 2003).

Predators around Bimini

The waters around Bimini are inhabited by 13 species of sharks, during different times of the year, and the Great Barracuda (*Sphyraena barracuda*). Four of the 13 species of shark were observed during this study. According to the IUCN Red List (2017), three of the shark species listed are near threatened: lemon (*Negaprion brevirostris*), blacktip (*Carcharhinus limbatus*), and bull sharks (*Carcharhinus leucus*) (IUCN 2019). Great barracuda are of least concern. Data deficiency is only seen in the nurse shark (*Ginglymostoma cirratum*).

Sharks

Elasmobranch fishes, particularly sharks, comprise one of the most widespread and diverse clades of marine predators, providing a model for refining predatory roles (Heupel et al. 2014). Larger sharks are considered apex predators, with most smaller species and small juvenile sharks being categorized as mesopredators (Heupel et al. 2014; Robbins and Renaud 2016). Sharks are considered to play an important role in community structure, occupying high positions in food webs, but there is conflicting evidence of their ability to control lower trophic levels species by direct and indirect ecological interactions (Heithaus et al. 2002; Brunnschweiler et al. 2014; Roff et al. 2016b; Bornatowski et al. 2017; Hansell et al. 2017;). Sharks exhibit a variety of hunting methods include burst speeds and agility, while also displaying suction, ram, bite, bite and gouge, and filter feeding methods (Motta and Wilga 2001; Robbins and Renaud

2016). Most marine top predators reside primarily where pelagic reef fish reside, with sharks being particularly abundant near reef islands, atolls, seamounts, and shelf breaks (Ketchum et al. 2014). They often exhibit inter-island movement between each of these formations. It is important to recognize the diversity of sharks within nearshore areas because different species have different behavior, life-histories, and influence as large top predators (Knip et al. 2010). Understanding their foraging behavior and spatial distribution is crucial in comprehending how they influence the behavior and populations of their prey.

Great Barracuda

The great barracuda is an economically, culturally, and ecologically important top predator that plays a key role in subtropical and tropical coastal marine environments (Schlaff et al. 2014; Becker 2016). In Bimini, barracuda are commonly found near the mangrove fringe, reefs, and shallow flats (De Sylva 1963; Newman et al. 2007). Barracuda typically forage twice a day, feeding in shallow habitats during the early morning and early evening (Catano et al. 2017). They will either stalk their prey or "sit-and-pursue" (remaining in a fixed position) then rush to attack prey within striking distance, which is equivalent to their body length, at velocities of ~12 m/s (26.8 mph) (Hiatt 1947; Gray 1957; Catano et al. 2017). Barracuda are characterized to drift while not actively feeding and lurk beneath the surface of the ocean (Hiatt 1947; De Sylva 1963). In the western North Atlantic, barracuda are observed in a variety of habitats, including near-shore reefs, tidal flats, and pelagic environments, and the species are thought to be an apex predator in near-shore systems (O'Toole et al. 2011; Daly-Engel et al. 2012). Young barracuda find protection in blades of seagrass (Thalassia) and adult barracuda are usually found in seagrass communities during high tide. Large barracuda are also common in the areas between seagrass and sand patches fringing a reef. Adult barracuda tend to avoid low salinity waters while juvenile species freely enter areas of low salinity in comparison (De Sylva 1963). It is suggested that barracuda are sensitive to sudden temperature changes, moving in and out with tidal waters, and transition from shallow to deeper strata as they mature (Newell and Imbrie 1955; De Sylva 1963). Being an abundant, large predator with selective habitat preference, barracuda could exert a

strong top-down pressure on fish communities across broad areas of warm coastal oceans (Becker 2016).

Prey around Bimini

In a BRUVs study by Burke (2015), the majority of sharks correlated with greater density of teleosts. Some of the more prominent teleost groups around the island are grunts (Haemulidae), porgies (Sparidae), jacks (Carangidae), wrasses (Labridae), snapper (Lutjanidae), triggerfish (Balistidae), and silversides (Atherinidae) (Burke 2015). Previously 128 species of teleosts were found within Bimini's mangrove and seagrass ecosystems in a seine study (Newman et al. 2007). These habitats are important due to their complexity, food availability, shelter, and protection they provide from predators. Although there is high diversity of prey communities in the seagrass community of Bimini, mangrove habitats exhibit higher biodiversity. South Bimini has a more favorable environment with more diversity, with many predatory juvenile species seeking the mangroves due to higher abundance of prey (Newman et al. 2007).

Baited Remote Underwater Video (BRUV) surveys

Studies using baited videos to examine marine systems started increasing in popularity in the mid-1990s and have become a popular technique to assess free-swimming species across the globe, particularly demersal fish communities (Hannah et al. 2014; Whitmarsh et al. 2017). Baited remote video survey instruments consist of a video camera inside an underwater housing mounted on a frame with a small, pre-weighed bait source attached to the end of a bait arm in the camera's field of view (Figure 1, Bond et al. 2012).

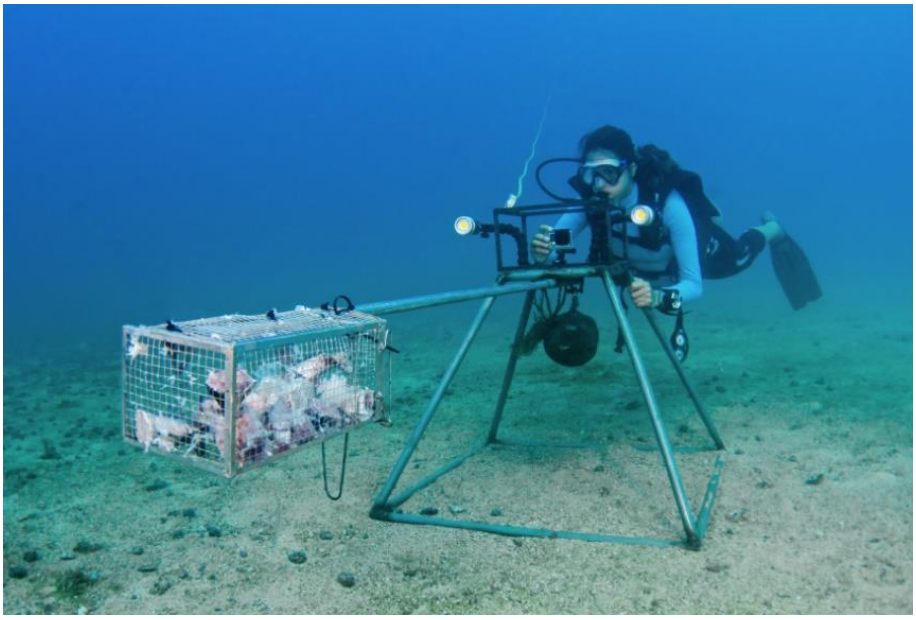

Figure 1. Representation of BRUVs method with camera and bait source (Adapted from Indo Ocean Project, 2017).

Deployments in reef areas are common in BRUVs research, followed by coral and rocky habitats (Whitmarsh et al. 2014). Velocity and direction of surrounding currents are key factors in determining fish attraction to the bait plume (Dunlop et al. 2015). The bait plume (blood and oil runoff from the chum block) attract fish down-current of the BRUV station and acts as an olfactory stimulus (Taylor et al. 2013). Baited remote underwater video systems are useful in accessing a wide range of depths and habitat types with minimal disturbance to the surrounding environment and without the aid of divers that can influence fish behavior (Harvey et al. 2012; Schobernd et al. 2014). Several studies employing BRUVs have been able to measure relative abundance of cartilaginous fish (chondrichthyans) and their prey, with recent extension into assessing chondrichthyan distribution at large spatial scales and across different habitat types, showing that BRUVs are an acceptable method to studying sharks and prey diversity (Bond et al. 2012; Clarke et al. 2012; Santana-Garcon et al. 2014; De Vos et al. 2015; Bond et al. 2012; Kilfoil et al. 2017). The BRUVs passive methodology also allows for its application in fragile and protected areas, in addition to dealing with rare and threatened species that may be negatively affected by more invasive gear or capture methods (Cappo et al. 2004).

Advantages

Subjects can be monitored without the potentially behavior-altering presence of a diver seen in other survey methods (Willis et al. 2000; Mallet and Pelletier 2014). Fisheries-dependent survey data used in stock assessment studies usually are collected via traditional fishing gear, such as gillnets, longlines, traps, and trawls. However, these capture methods can be limited by depth, selectivity, bathymetry with high rugosity, and fish behavior (Campbell et al. 2015). In MPAs, assessments of relative abundance, in many cases, must be conducted using less destructive techniques to avoid negative population impacts (Assis et al. 2008).

Baited video-based techniques are proving useful in assessing the efficacy of MPAs and have become a useful tool in fisheries management (Taylor et al. 2013; Campbell et al. 2015; Dunlop et al. 2015)**.** The BRUVs system does not require the physical capture of animals and is cost-effective and accessible compared to methods such as diver-based underwater visual census (UVC) and traditional fishing gear. In comparison with traditional capture-based methods, BRUVs provide a non-destructive, non-invasive, easy to replicate, low risk to personnel alternative sampling method and cause minimal damage to benthic environments (Cappo et al. 2004; Cappo et al. 2007; Brooks et al. 2011; Harvey et al. 2012; Santana-Garcon et al. 2014a; Whitmarsh et al. 2014; Kilfoil et al. 2017). Baited remote underwater video surveys have strong monitoring potential and can provide estimates of species community composition, relative abundance, size of individuals, and in some species, sex of individuals (Colton and Swearer 2010; Campbell et al. 2015). Data can also include time of first arrival of animals, maximum number of individuals viewed, standard catch per unit effort, relative abundance, diversity, and distribution of large-bodied fish communities (Brooks et al. 2011). While UVC surveys are often able to determine the abundance and distribution of sharks, they are limited by short survey times, species mobility habits, and may be impacted by behavioral response to human activity, depth, and visibility limitations (Colton and Swearer 2010; Lowry et al. 2012). When assessing species relative abundance, BRUVs can minimize the potential impacts of diver disturbance as a more passive methodology and may show less species bias in some communities.

Baited remote underwater video surveys are not size selective of animals surveyed compared to other methods and can be replicated at most depths in multiple habitat types (Brooks et al. 2011; Taylor et al. 2013; De Vos et al. 2015). They are a practical and simplified survey method and have become more prevalent in recent years. In a study by Colton and Swearer (2010), BRUVs provided information on teleost species that were not captured by demersal longlines due to the selectivity of the hooks or bait (McLean et al. 2015). Baited remote underwater video surveys are also require less boat time and less personnel than other methods such as longline surveys and UVCs (Willis et al. 2000; Colton and Swearer 2010; Brooks et al. 2011). Video quality has improved over the years, and with initial investment costs decreasing as components (cameras etc.) become more readily available, it is now more affordable for researchers to deploy multiple BRUVs simultaneously (Cappo et al. 2004; Harvey et al. 2007). Greater availability increases the potential for greater replication and spatial coverage of sampling. Baited remote videos also opportunistically observe animals that are not interested in the bait but have just happened to swim by (Schobernd et al. 2014). Recordings minimize observer bias and misidentification compared to UVCs (Santana-Garcon et al. 2014a). Videos also provide a permanent record of data that allows different ecological questions to be asked at a later date (Harvey et al. 2013; Kilfoil et al. 2017).

Disadvantages

The performance of BRUVs is governed by light levels and water clarity at each site. In deeper water, moderate levels of turbidity can drastically alter the ability to identify and count fish in the field of view (Cappo et al. 2004). The BRUVs techniques have shown promise in overcoming some limitations of UVC, yet they remain unable to provide an absolute measure of density in any environment under any conditions (Colton and Swearer 2010; Taylor et al. 2013). Identifying sex of a shark during observation is less likely using BRUVs. Brooks et al. (2011) found that in 97.8% of longline studies, sex was able to be determined, while only 39.8% of BRUV studies were able to determine the sex of animals. Similarly, Mono-BRUVs are unable to determine accurate size measurements and data quality can be limited due to the accuracy of species identification (Brooks et al. 2011). Size measurements, however, could be determined

using BRUVs by incorporating stereo-video techniques (Harvey et al. 2007; Brooks et al. 2011). Additionally, BRUVs have a higher time requirement in post-processing than non-baited remote underwater video surveys, as BRUVs often attract more species and individuals (Mallet and Pelletier 2014).

Baited remote underwater video surveys may introduce their own biases in community assessment where carnivorous species and malnourished individuals may be drawn to the bait where others may be missed. Users of BRUVs on shelf and coastal reefs have ignored bait plume dispersal, the slick of blood and oil secreted by bait, and have used inconsistent abundance indices during short sets (10 to 90 min) to estimate patterns of relative abundance (Harvey et al. 2007). Different types of bait may influence the numbers of individuals and species attracted to the bait and the distance over which a fish is attracted. Seasonal, reproductive, and lunar patterns of activity in the swimming speed, schooling behavior, and appetite of the fish presumably also affect the attraction of fish to a bait (Harvey et al. 2007).

Attraction by similar species, presence or absence of predators, and home range size are also factors that challenge the effectiveness of BRUVs (Harvey et al. 2007).Where there are large numbers of a single species, there may be an underestimation of relative abundance and species richness (Lowry et al. 2012; Taylor et al. 2013; Kilfoil et al. 2017). On the contrary, resampling of individuals may be an issue as individual fish may be counted more than once over the course of a deployment if they leave and re-enter the field of view, potentially inflating the sample size for certain species (Schobernd et al. 2014; Kilfoil et al. 2017). Baited remote underwater video surveys have been used extensively in west Australia to assess fish assemblages in coastal and continental shelf environments where it has been determined that although useful, there is an upper limit as to the number of individuals that can be viewed in the frame (Willis et al. 2000; Colton and Swearer 2010). Overall, studies using BRUVs technology are not standardized in published research deployments, with a wide variability in the construction, experimental design, and implementation (Whitmarsh et al. 2017). Establishment of a standardized bait type, amount, and frame design would allow for accurate comparisons of diversity and abundance across studies (Burke 2015).

Standard BRUVs using one camera (mono camera) may bias abundance estimates through saturation at high densities and low detection probability for rare or cryptic species (Lowry et al 2012; Kilfoil et al. 2017). Cameras with a restricted field of view (FOV) may reduce detection of elasmobranchs and teleosts with non-uniform spatial distribution around the camera (Campbell et al. 2015). For example, an area with a true density of 10 sharks may have a maximum number of five individuals in the FOV. Reduced detections of species and individuals will impact count data of relative abundance through inflated zero (0) counts (Campbell et al. 2015; Cortés et al. 2015; Kilfoil et al. 2017). Full-spherical (FS) cameras, on the other hand, provide an increase in FOV with a 360° view, resulting in higher shark counts compared to standard mono cameras by 12 % (Kilfoil et al. 2017). A study comparing FS and mono cameras determined how limited FOVs of mono cameras may reduce the effectiveness of monitoring shark populations in regions where abundances are particularly high in addition to having a lower probability of detecting sharks at all. In any video survey, a non-occurrence of species is marked as zero (0). However, a species may have been present although not detected by either FS or mono cameras. This "false" absence may lead to a bias in estimates of absolute detection probability (Kilfoil et al. 2017).

Hypotheses and Objectives

With this study, I assess the carrying levels of predation risk inherent to multiple habitats around Bimini and their impacts on the prey community composition. I shall investigate the change in impact of predator type (active foragers – sharks; vs ambush predators – barracuda) on prey communities using BRUV surveys. I aim to:

1. Quantify and assess if species richness and relative abundance of prey fish communities differ between high and low risk habitats.
    - Ho: There is no significant difference in prey fish communities between high risk and low risk areas
    - Ha: There is a significant difference in prey fish communities between high risk and low risk areas
2. Will prey abundance vary among sites and can a relationship of abundance between predators and prey be made?

a. What is the most abundant predator at each site?
b. What do the predator and prey communities look like across the different habitats?
    - Ho1: Prey abundance does not vary among sites.
    - Ha1: Prey abundance does vary among sites.
    - Ho2: There is no relationship between abundance of predator and prey.
    - Ha2: There is a relationship between abundance of predator and prey.

3. Determine if prey species behaviors differ by predator-species (shark vs barracuda)
    a. Do prey communities show a difference in foraging/vigilance behavior in areas of high or low predation risk.
        - Ho: There will be no significance between prey behaviors by predator-species.
        - Ha: There will be significance between prey by predator-species.
4. Assess a variety of environmental parameters: date and time of deployment, current velocity (cm/s), depth (m), dissolved oxygen (mg/L), salinity (ppt), secchi distance (m), temperature (°C), tidal phase, and habitat sampling.
    a. What are the effects of environmental factors on community composition?
    b. What are the effects of environmental factors between high and low risk areas?
    c. What are the effects of environmental factors on abundance of functional groups in the two locations?
        - Ho1: There is no association between environmental factors and community composition.
        - Ha1: There is an association between environmental factors and community composition.
        - Ho2: There is no association between environmental factors and abundance of functional groups in the two locations.
        - Ha2: There is an association between environmental factors and abundance of functional groups in the two locations.

Methods

Study Area

This study examined shark, barracuda, and teleost diversity and abundance around the Bahamian island of South Bimini and how predator-prey interactions influence risk behavior. This is a continuation on a previously published methodology in the system which utilizes a larger dataset previously collected to enhance this current thesis (Burke 2015). For this study, shark, barracuda, and teleost prey diversity and abundance were examined over a six-month period— January to June 2018. The framework of this study is an extension of a previous study, but all data analyzed was taken only from this six-month period. Observations were conducted using baited remote underwater video surveys (BRUVs) in diverse habitats (Table 1, Figure 2), using two concurrent deployments on the north (low risk; 50 sites) and south sides (high risk; 50 sites) of South Bimini (Figure 3). BRUVs were not simultaneously deployed within 500 m of one another at depths ranging from 0.7-5.3 meters. Abundance at each site was compared in order to determine if predator abundance affected prey abundance in high (south side of South Bimini) and low (north side of South Bimini) risk environments. Although the great barracuda is a teleost, they were classified as a predator in this experiment with the shark species. All other teleosts were classified as prey.

Location	Habitat
North of South Bimini	Low density Thalassia and Halodule, Sargassum; patches of mangroves and sand along the shore.
South of South Bimini	Patches of low, medium, and high densities of Thalassia and Halodule, Sargassum; dense mangroves fringed along the shore.

Table 1. Sampling locations with corresponding habitat coverage.

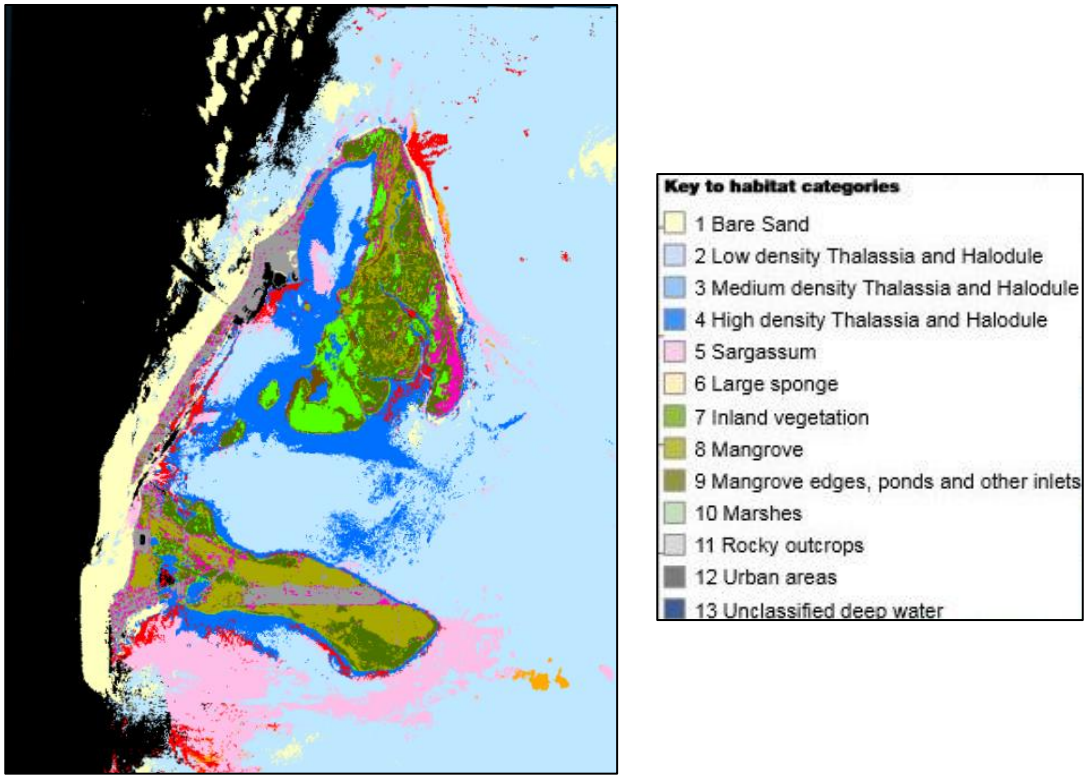

Figure 2. Habitat map of Bimini, The Bahamas with legend (Save Our Seas Foundation 2019).

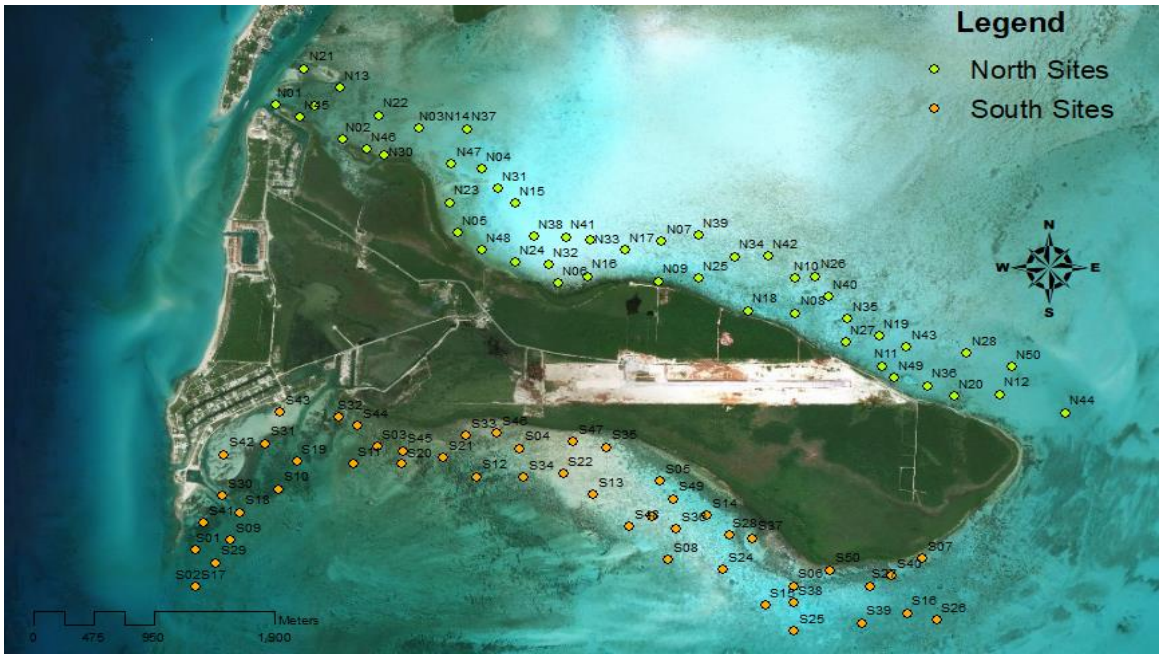

Figure 3. Map of the 50 deployment sites on the south side of South Bimini and 50 deployment sites north of South Bimini (Google Earth Pro 2019).

Research was conducted at the Bimini Biological Field Station Foundation "Sharklab" in Bimini, The Bahamas. Bimini (25°44' N, -79°16' W) is a marine environment located in the tropical Atlantic comprised of two small subtropical islands, North Bimini and South Bimini, separated by a channel, located in the Northwest corner of the Commonwealth of the Bahamas archipelago (Figure 4B; Taylor et al. 2012; Trave and Sheaves 2014). The islands of Bimini lay approximately 86 km (53 miles) east of Miami, along the Gulf Stream on the western edge of the Great Bahama Banks (Figure 4A Jennings et al. 2012; Burke 2015; Hansell et al. 2017). The island provides critical nursery habitats and food resources for many marine organisms, and many that are important species of ecological and economic value (Trave and Sheaves 2014). Its climatic and geographic conditions allow for the development of diverse ecological communities such as coral reefs, seagrass beds, mangrove forests, sandflats, and banks (Trave and Sheaves 2014). Its various ecosystems and abundant resources make Bimini an area of rich biodiversity.

The average water temperature in Bimini is between 21-29° C annually. The Bahamas and the Caribbean are characterized by a dry winter-wet summer pattern with a "midsummer drought" from June-July (Taylor et al. 2012; Jennings et al. 2012). The annual dry cool season in Bimini occurs November/December to April (21-24° C) with the wet warm season occurring between May to November/October (27-29° C) (Taylor et al. 2012; Newman et al. 2007). Dry and wet seasons are characterized by the amount of rainfall and changes in the tropical Atlantic and tropical Pacific (Taylor et al. 2012). Wet season exhibits and increase in wave action, precipitation, humidity, and other tropical weather such as tropical depressions, hurricanes, and other storms.

Figure 4. (A) Satellite images of Bimini, The Bahamas in relation to the Miami coast. (B) Satellite image of both North and South Bimini, The Bahamas (Google Earth Pro 2019).

The BRUVs sampling frames at the Bimini Biological Field Station are constructed of stainless-steel bars forming a trapezoidal shape (base of 80 x 95 cm, height of 80 cm, and camera mount 55 cm from the ground). A removable stainless-steel bait arm extends 1.7 meters from the camera mount with a bait box (34 cm x 20 cm x 10 cm) attached to the end. The bait box rests 50 cm off the substrate, allowing the bait plume to remain undisturbed by obstacles and for optimal flow through the bait box (Figure 6).

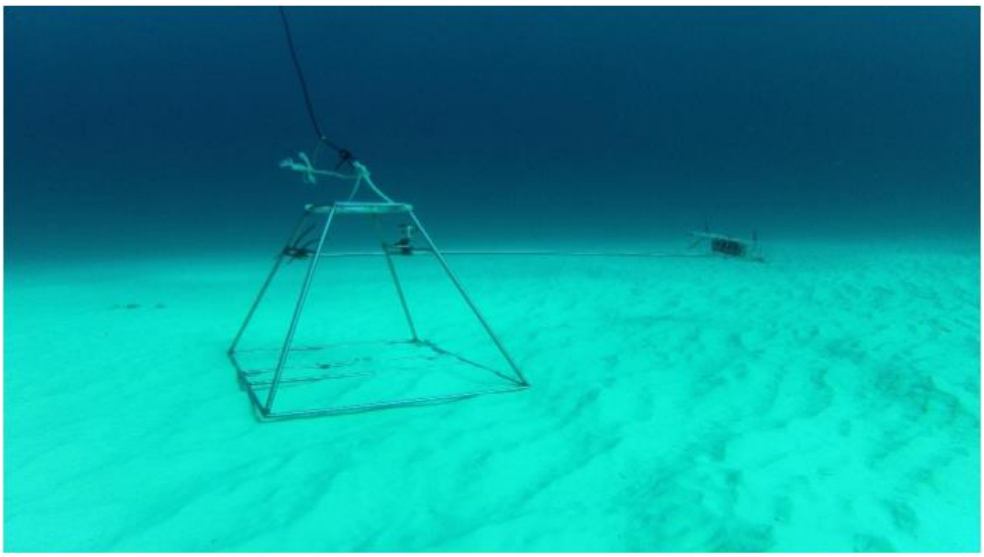

Figure 6. A standard BRUVs deployment in Bimini, The Bahamas, illustrating its design with the GoPro® facing the bait box and the rope that leads up to the buoy (Burke 2015).

A GoPro® camera (HERO model) was attached to the camera mount at the base of the bait arm and used to record all organisms in the FOV. The frozen chum block placed inside the bait box maintained a continuous bait plume in the presence of varying water temperatures, current velocity, and feeding events. Location and environmental parameters were recorded and the BRUV was deployed for 60 minutes for each deployment. Menhaden chum was placed into the bait box facing downstream so species would come into the FOV from downstream, moving up into the chum slick. Menhaden is a bloody, oily fish in the herring family that produces a good chum slick for attracting fish. Some studies have been done in regards to bait types and concluded that fish in the herring family Clupeidae (sardines and menhaden) have been found to be productive as bait fish (Cappo et al. 2006). Fish in the herring family are the most commonly used across BRUVs studies for this reason.

Cameras were set to record in 1080p at 30 frames per second to record at the best possible resolution for all cameras. Fluorescent surface floats marked the unit at the surface to avoid the possibility of other vessels striking the rope or frame and to help facilitate relocation of the equipment at the end of deployment. During deployments, the stainless-steel frames were lowered to the sea floor from a research vessel by rope, avoiding delicate organisms where possible (e.g., coral, sponges). Frames were removed from the seafloor in the same manner. Video clips were stitched together using Windows Movie Maker software (2012) to enable continuous video footage for each deployment. To reduce observer bias, videos were reviewed in real-time by at least two observers in the laboratory. This also ensured higher accuracy of species identification. The data collected was used to record relative abundance, distribution, and species richness.

The date and time of deployment, location (latitude/longitude), cloud cover (%), current velocity (cm/s), current direction (degrees), depth (m), dissolved oxygen (mg/L), salinity (ppt), turbidity (secchi distance - m), temperature (°C), tidal phase, wind speed (knots), wind direction, and sea state were recorded before each deployment. Habitat type was determined during the data entering phase. North was classified as “lagoon” and south was classified as “flat”. The bait arm was directed down current once the frame was at the sea floor to ensure all organisms that approached were from the down-current direction in line with the FOV (Cappo et al. 2006, Santana-Garcon et al. 2014b; Burke

2015). The standard bait used was one-third of a frozen menhaden (*Brevoortia tyrannus*) chum block (1kg) per deployment.

Instrumentation

Salinity, temperature, and dissolved oxygen were measured using a YSI Pro2030® dissolved oxygen and salinity multiparameter instrument. Current velocity was recorded using a mechanical flow meter (General Oceanic) with a low velocity paddle; recorded in rotations per minute (rpm). Locations with a depth of 1.75m or greater were recorded using a dive computer (SUUNTO).

To determine turbidity, a secchi disk was submerged parallel to the research vessel. This parallel position is a better representation of "the visual sensory capabilities of marine organisms attracted to the bait at that time" (White et al. 2013). The distance was recorded as a horizontal value rather than the traditional vertical measurement. An observer swam away from the vessel, perpendicularly on the ocean surface, while keeping an eye on the secchi disk. Once the disk was no longer in sight, the distance was recorded, in meters, using a measuring tape to determine visibility. This was completed before each BRUVs deployment at the selected site. Tide charts obtained from the National Oceanic and Atmospheric Administration (NOAA) assisted in recording tidal phase.

Data Set

A full-page data set structure portrays shark and teleost assemblage data, location, time observed, number of observations, and establishment of first appearance or MaxN (Table 2). This table shows what has been seen in the area per location. This is an extension of previous datasets and helps to quantify the assemblage by calculating the relative abundance of sharks, great barracuda, and teleosts. Only new data from this six-month study were analyzed.

Set_Code	Obs_Time	Genus	Species	Common Name	Measur-able	Event_Tag
BIN_N01	0:17:07	Caranx	ruber	Bar jack	1	First appearance
BIN_N01	0:30:25	Ostraciidae		Boxfish sp.	1	First appearance
BIN_N01	0:10:31	Sphyraena	barracuda	Great barracuda	2	MaxN
BIN_N01	0:13:48	Lutjanus	synagris	Lane snapper	1	First appearance
BIN_N01	0:54:15	Negaprion	brevirostris	Lemon shark	1	First appearance
BIN_N01	1:02:12	Lutjanus	analis	Mutton snapper	1	First appearance
BIN_N01	0:44:43	Ginglymostoma	cirratum	Nurse shark	1	First appearance
BIN_N01	0:48:46	Acanthurus	tractus	Ocean surgeonfish	3	MaxN
BIN_N01	0:45:43	Sparidae		Porgy sp.	4	MaxN
BIN_N01	1:02:40	Scarus	vetula	Queen parrotfish	3	MaxN
BIN_N01	0:47:23	Malacanthus	plumieri	Sand tilefish	1	First appearance
BIN_N01	0:58:10	Halichoeres	Bivittatus	Slippery dick	3	MaxN
BIN_N01	1:02:18	Haemulon	Plumieri	White grunt	2	MaxN
BIN_N01	0:44:43	Echeneis	Neucratoides	Whitefin sharksucker	1	First appearance
BIN_N01	0:44:38	Caranx	bartholomaei	Yellow jack	1	First appearance
BIN_N01	0:31:39	Gerres	cinereus	Yellowfin mojarra	1	First appearance

Table 2. An example dataset for one deployment sorted by location, shark and teleost assemblage data, time observed, number of observations, and establishment of first appearance (measurable = 1) or MaxN (measurable = >1).

Data Analysis

Baited remote underwater video recordings were reviewed after deployment. The maximum number (MaxN) of each species in the video frame at one time for each hour of BRUVs deployment footage was counted and recorded. Biodiversity was assessed by the number of species present in all videos. Common name, number of observations, time of first appearance and time of MaxN were also recorded. Functional groups were defined as herbivorous, piscivorous, and planktivorous fish and abundance was assessed through direct counts and compared between sites using analysis of similarity (ANOSIM). Using ANOSIMs, functional groups were broken down into higher taxonomic groups such as family, genus, and species (e.g., grunts, porgies) as sample size allowed. Groups were broken down further when samples allowed in order to investigate finer scale diversity (Burke 2015).

Composition

An ANOSIM was run using PRIMER (Clarke and Gorley 2015) to assess whether there was a significant difference between the composition of two sites with multiple replicates within each site. All species were categorized across both sites and a matrix was created from the input of composition data to compare sites. Since ANOSIM analysis showed differences in assemblages, a similarity percentage (SIMPER) analysis was used to assess what main species differed between the groups at each of the two sites by comparing the percentage of contribution to the total number of species (sum of MaxN and first appearance) found in each location.

Abundance

An ANOSIM was used to compare species abundance by functional group between high and low predation risk sites. Teleost and predator species were grouped into feeding behavior functional groups across both sites: planktivorous, herbivorous, and piscivorous. All species were categorized into functional groups across both sites. The non-numeric (reef (BIN or BIS), habitat (lagoon or flat), current flow (high, medium, low), tidal state (ebb and flow), and wind direction (N, NE, NW, S, SE, SW, E, W)) factors were combined with functional group data to determine which environmental

factors most adequately define the data. A SIMPER analysis was used to assess which functional group was the most dominant between the two sites and determined percentage of contribution to the total number of groups found in each location.

Environmental Parameters

Linking biotic assemblage patterns to the "best" subsets of environmental variables was completed using BEST analysis within the PRIMER statistical program. The analysis is used to find the best match between the multivariate among-sample patterns of an assemblage and the environmental variables associated with those samples. This analysis was used to show the importance of environmental parameters (date and time of deployment, current velocity (cm/s), depth (m), dissolved oxygen (mg/L), salinity (ppt), secchi distance (m), temperature (°C), tidal phase, and habitat type) on the diversity of families and higher taxonomic groupings (Burke 2015). Rank correlations within BEST analysis showed which environmental data best characterized community composition.

Results

There were 100 sets of environmental data from 50 locations on the north side of South Bimini and 50 locations on the south side of South Bimini. For each location, there were 60-minutes of video for analysis containing species abundance data. In total, there were 120 deployments due to equipment failures and ebbing tide leaving the camera out of water. Twenty videos were not used because multiple locations were resampled due to these malfunctions (no environmental data due to equipment failure, video cut short due to battery failure, or tide going below the camera). Community composition is evaluated through a series of analyses to determine relationships between species and the environment.

Hypothesis 1- Variation in Prey Richness and Abundance

To quantify and assess if species richness and relative abundance of prey fish communities differed between high and low risk habitats, overall species count on North and South sites of South Bimini were run through a t-test in R Studio. On South Bimini,

teleost and predator species counts on the north side equaled 1,376 while the south side contained a count of 5,723, for a total of 7,099 individuals counted. Of the total 7,099 individuals counted, 7,004 were teleosts with 1,334 south and 5,670 north of South Bimini. The north sites contained 19.4% of the total population counted and the south sites contained 80.6%. The mean of species south of South Bimini was 113.4 and the mean number of species north of South Bimini was 26.7. Figure 5 below shows the comparison of location-based prey counts of individuals.

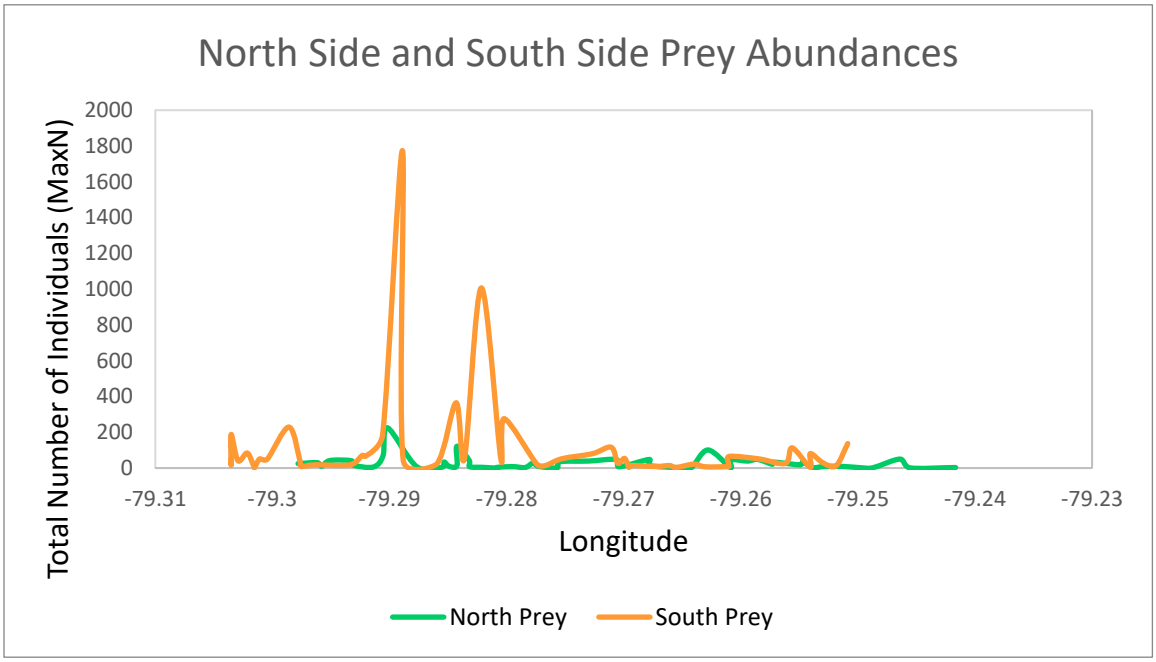

Figure 5. The comparison of number of prey species North of South Bimini (green) and South of South Bimini (orange) at each site (N01-N50, S01-S50).

A two-sample t-test compared total abundance (North=1,376, South=5,723) data between north and south sides of South Bimini. To evaluate the variances of the two groups, the Fisher's F-test was used to verify the homogeneity of variance. The variances of the two groups (North and South) were not homogenous (p-value of < 2.2e-16. There was a significant difference in total predator and prey communities between high risk and low risk areas (Welch's two sample t-test, p-value = 0.03668). The same statistical test was run on total prey species count in low risk and high risk areas (North=1,334, South=5,670, respectively). There was a significant difference in prey fish communities between high risk and low risk areas (Welch's two sample t-test, p-value = 0.03718).

Hypothesis 2- North and South Site Prey Assemblages

For all analyses, site 24 on the north side of South Bimini was removed from the abundance dataset and environmental dataset because zero species were counted during video analysis. Site 43 on the north side of South Bimini was also removed as an outlier from abundance analysis and environmental analysis. A non- metric multi-dimensional scaling model (MDS) revealed site 43 was an infinite distance away from all other points, creating a dense cluster of all the other sites on the graph, making the differences indistinguishable from one another. Removal of site 43 on the north side allowed for a more meaningful plot and a better visual representation of the data. The shark, barracuda, and teleost count data were square root transformed. Count data was combined in excel with non-numerical environmental factors including reef (BIN or BIS), habitat (lagoon or flat), current flow (high, medium, low), tidal state (ebb and flow), and wind direction (N, NE, NW, S, SE, SW, E, W). Assessing raw species abundances, transforming data contributed in downweighing the importance of the highly abundant species so that similarities depend on both the higher abundance values and those of less common species (Clark et al. 2014). Bray-Curtis similarity was used to find the similarity in the data so that an ANOSIM and MDS could be completed. Bray-Curtis coefficient has become common in ecology as a similarity measure that creates a data matrix for the analysis of similarity of abundance data (Clarke and Gorley 2015). Similarities calculated on original abundance values can be over-dominated by a small number of highly abundant species, failing to reflect similarity of overall community composition (Clark et al. 2014).

An MDS is a graphic representation made from ranks of similarities within the data, with an aim to represent the samples in a low-d space (2-D and 3-D). A higher input of restarts (250) reduced the stress of making the data fit into the graph. The higher the stress, the more the data are distorted to try to fit it. Additionally, inputs for MDS were minimum stress of 0.01 and Kruskal fit scheme of 1. Non-metric MDS models construct a configuration of the samples in a specific number of dimensions. Stress on the graph less than 0.2 gives a potentially useful 2-dimentional picture. A cross-check of conclusions were checked using ANOSIM analysis. The 2-D configuration stress measure of the data is 0.21. The 3-D configuration stress measure is 0.16. Distances

between the data were matched as closely as possible to relative dissimilarities based upon the resemblance matrix. The closer the plot points are to each other, the more similar the community composition.

The BEST (Bio-Env) procedure matches biotic data to environmental patters. The BEST analysis uses Spearman rank correlation method, Euclidean distance resemblance matrix data, and permutations (999) to evaluate if abundance differs among sites. Prey abundance does differ longitudinally (North versus South) (BEST analysis, p-value = 0.01, rho = 0.187).

SIMPER analysis then broke down the Bray-Curtis similarity within each group into prey species contribution and assessed differences between the two groups. The groups of the north side and the south side show the contributions of each species to the Bray-Curtis similarity within each site. SIMPER analysis (one-way factor design) was used on raw species counts (square root transformed) to find the percent of similarity and dissimilarities of abundance counts for each reef (North and South). SIMPER used Bray-Curtis similarity, listing only higher contributing variables with a cut off percentage of 90% to avoid a long list of all species, however small their percent contribution is to the average dissimilarity between two groups.

North Side					
Average similarity: 17.15					
Species	**Av.Abund**	**Av. Sim**	**Sim/SD**	**Contrib%**	**Cum. %**
Antherinidiae	2.26	8.21	0.43	47.88	47.88
Halichoeres bivittatus	1.01	5.06	0.56	29.51	77.38
Caranx ruber	0.34	0.96	0.23	5.26	83.00
Calamus penna	0.26	0.81	0.16	4.70	87.70
Echeneis neucratoides	0.24	0.53	0.18	3.10	90.80

Table 3. The average abundance, similarity, standard deviation, contribution percentage, and cumulative percentage of prey species to the north side of South Bimini.

Analysis of the north side shows the contribution of each species to the Bray-Curtis similarity (Table 3). The Bray-Curtis average (mean) similarity between all pairs of sites on the north side was 17.94, primarily composed of five species: silversides (47.8% of the total), slippery dicks (29.5% of the total), bar jacks (5.2% of the total), sheepshead porgies (4.7% of the total), and whitefin sharksuckers (3.1% of the total).

These species have a cumulative contribution of 91.3% of the total within group similarity. These species are defined as typical of the north side.

South Side					
Average similarity: 25.59					
Species	**Av.Abund**	**Av. Sim**	**Sim/SD**	**Contrib%**	**Cum. %**
Halichoeres bivittatus	2.81	14.64	1.37	57.22	57.22
Antherinidae	3.60	3.64	0.32	14.21	71.44
Calamus penna	0.79	2.27	0.44	8.88	80.31
Caranx ruber	0.68	1.64	0.42	6.39	86.70
Hemiramphus brasiliensis	0.51	0.80	0.26	3.14	89.85
Sphoeroides testudineus	0.31	0.47	0.21	1.84	91.68

Table 4. The average abundance, similarity, standard deviation, contribution percentage, and cumulative percentage of prey species to the south side of South Bimini.

The Bray-Curtis average similarity between all pairs of sites on the south side was 25.59, primarily composed of six species: slippery dicks (57.2% of the total), silversides (14.2% of the total), sheepshead porgies (8.8% of the total), bar jacks (6.3% of the total), ballyhoo (3.4% of the total), and checkered puffers (1.8% of the total) (Table 4). These species have a cumulative contribution of 91.6% of the total within group similarity. These species are defined as typical of the south side.

The average dissimilarities between all pairs of sites is 82.02 and is made up of a list of 31 species (Table 5). The same similarity analysis was used to determine which predator species contributed most to the similarities and dissimilarities between sites (Table 6, Table 7, and Table 8).

North Side and South Side						
Average dissimilarity = 82.02						
Species	**North Av. Abund**	**South Av. Abund**	**Av. Diss**	**Diss/SD**	**Contrib %**	**Cum. %**
Antherinidae	2.26	3.60	19.25	0.89	23.47	23.47
Halichoeres bivittatus	1.01	2.81	12.02	1.11	14.65	38.13
Calamus penna	0.26	0.79	5.04	0.69	6.15	44.28
Caranx ruber	0.34	0.68	4.22	0.68	5.15	49.43
Hemirapmhus brasiliensis	0.32	0.51	3.87	0.55	4.72	54.15
Sphoeroides testudineus	0.10	0.31	2.26	0.45	2.75	56.90
Engraulidae	0.38	0.33	2.22	0.28	2.70	59.60
Ocyurus chrysurus	0.07	0.55	2.00	0.46	2.44	62.03
Haemulon plumieri	0.25	0.37	1.98	0.56	2.42	64.45
Gerres cinereus	0.28	0.12	1.97	0.35	2.40	66.85
Echeneis neucratiodes	0.24	0.21	1.89	0.54	2.30	69.16
Caranx bartholomaei	0.10	0.31	1.79	0.42	2.18	71.34
Clupeidae	0.00	0.63	1.48	0.14	1.81	73.15
Lutjanus synagris	0.20	0.18	1.39	0.55	1.69	74.84
Lutjanus analis	0.07	0.24	1.37	0.48	1.67	76.51
Thalassoma bifasciatum	0.04	0.33	1.19	0.44	1.45	77.96
Calamus pennatula	0.00	0.21	1.00	0.31	1.23	79.18
Caranx crysos	0.05	0.18	1.00	0.39	1.22	80.41
Carangidae	0.15	0.05	0.98	0.27	1.20	81.60
Lutjanus griseus	0.16	0.10	0.94	0.33	1.15	82.75
Acanthurus tractus	0.12	0.13	0.76	0.39	0.92	83.68
Tylosurus crocodilus	0.06	0.09	0.65	0.32	0.79	84.46
Eucinostomus gula	0.12	0.03	0.63	0.22	0.77	85.24
Canthidermis sufflamen	0.00	0.19	0.61	0.42	0.75	85.99
Serranidae	0.02	0.11	0.59	0.31	0.72	86.71
Echeneis naucrates	0.04	0.04	0.50	0.26	0.61	87.32
Balistes vetula	0.00	0.17	0.48	0.32	0.59	87.90
Halichoeres poeyi	0.04	0.09	0.47	0.26	0.58	88.48
Haemulidae	0.05	0.07	0.47	0.23	0.57	89.05
Platybelone argalus	0.07	0.00	0.45	0.22	0.55	89.60
Scombermorus regalis	0.00	0.11	0.43	0.30	0.52	90.12

Table 5. SIMPER analysis of prey species contribution, in decreasing order of contribution, to the north side and south side of South Bimini. Shows the dissimilarities between groups.

Great barracuda and lemon sharks contributed to the similarity between sites on the north side (Table 6) and great barracuda contributed to the similarity between sites on the south side of the island (Table 7). Additionally, piscivorous fish were the functional group that contributed to the similarity between sites to both the north side and the south

sides of South Bimini (over 70% of the similarity at the north and south sides), followed by planktivorous species (Table 9, Table 10).

North Side					
Average similarity: 15.91					
Species	**Av.Abund**	**Av. Sim**	**Sim/SD**	**Contrib%**	**Cum. %**
Sphyraena barracuda	0.38	10.93	0.41	68.70	68.70
Negaprion brevirostris	0.28	4.40	0.27	27.66	96.36

Table 6. SIMPER analysis of predator species contribution to the similarity between sites on the north side of South Bimini.

South Side					
Average similarity: 23.64					
Species	**Av.Abund**	**Av. Sim**	**Sim/SD**	**Contrib%**	**Cum. %**
Sphyraena barracuda	0.54	22.68	0.57	95.92	95.92

Table 7. The average abundance, similarity, standard deviation, contribution percentage, and cumulative percentage of predator species to the north side of South Bimini.

North Side and South Side						
Average dissimilarity = 81.31						
Species	**North Av.Abund**	**South Av.Abund**	**Av. Diss**	**Diss/SD**	**Contrib%**	**Cum.%**
Sphyraena barracuda	0.38	0.54	46.59	1.10	57.30	57.30
Negaprion brevirostris	0.28	0.11	20.50	0.66	25.22	82.52
Ginglymostoma cirratum	0.10	0.09	9.03	0.44	11.11	93.62

Table 8. The average abundance, similarity, standard deviation, contribution percentage, and cumulative percentage of predator species to the south side of South Bimini.

North Side					
Average similarity: 45.11					
Species	**Av.Abund**	**Av. Sim**	**Sim/SD**	**Contrib%**	**Cum. %**
Piscivorous	2.46	32.74	1.32	72.57	72.57
Planktivorous	2.62	10.41	0.49	23.08	95.65

Table 9. The average abundance, similarity, standard deviation, contribution percentage, and cumulative percentage of functional groups to the north side of South Bimini.

South Side					
Average similarity: 52.09					
Species	**Av.Abund**	**Av. Sim**	**Sim/SD**	**Contrib%**	**Cum. %**
Piscivorous	2.46	32.74	1.32	72.57	72.57
Planktivorous	4.87	8.48	0.52	16.26	94.13

Table 10. The average abundance, similarity, standard deviation, contribution percentage, and cumulative percentage of functional groups to the south side of South Bimini.

A Kendall's rank correlation test was used to evaluate the relationship between the abundance of predator and prey. Kendall's rank correlation is a non-parametric test that measured the strength of dependence between these two variables and can handle ties (data points have identical numerical values) within the data (Neuhauser and Ruxton 2009). The Kendall's rank p-value showed there was no relationship between abundance of predator and prey (p-value = 0.6009).

Hypothesis 3- Prey Behavior by Predator Species

There was a total of 36 sharks and 59 barracuda that came into the field of view (MaxN). The objective was to determine if prey species have differing behavioral responses when in the presence of sharks versus barracudas. The definition of the response, in this experiment, was "flight response" which was characterized by prey species fleeing the field of view within 5 seconds of the predator appearing on screen. A score of presence (1) and absence (0) of flight response of prey was given to each shark and barracuda in the dataset. There were five videos containing flight responses to sharks compared to 16 videos featuring flight responses to barracudas. The objective was to analyze if prey responded to one predator guild over the other. There was no significance between prey and their behaviors by predator-guild (Pearson's chi-square test, p-value = 0.16). Within the videos containing flight responses, there were multiple flight responses from numerous individuals of the same prey species to one individual predator. Sharks provoked 32 flight responses overall and barracuda elicited 27 flight responses (Figure 7). There was no relationship between flight responses by predator guild (Pearson's chi-squared test, p-value = 0.07477). Prey communities also did not show a difference in foraging or vigilance behavior in areas of high or low predation risk (Wilcoxon rank sum test, p-value 0.3333).

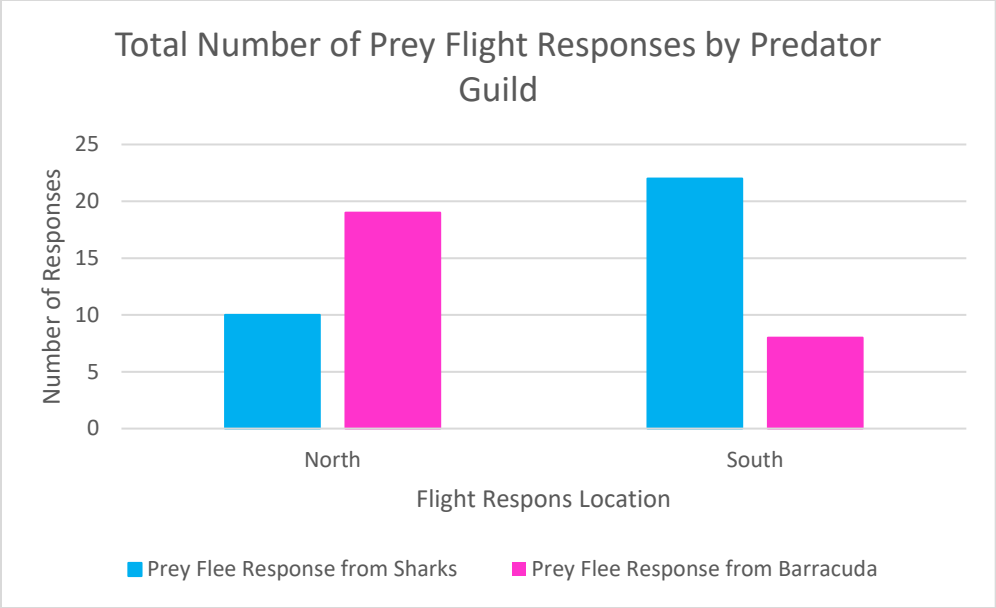

Figure 7. Representation of prey flight responses to shark and barracuda on North and South sites.

Hypothesis 4- Environmental Effects on Community Composition

Using ANOSIM and BEST analysis, an association between environmental factors and community composition were analyzed. An ANOSIM describes if there is an effect of the data or not. A resemblance matrix within ANOSIM tests for assemblage differences between groups of samples specified by the levels of a factor (Clarke and Gorley 2006). To test environmental parameters, BEST analysis was used to find the best match between the multivariate among-sample patterns of an assemblage and the environmental variables associated with those samples (Clarke and Gorley 2015). The extent of matches between among-sample patterns reflects the degree to which the abiotic data 'explains' the biotic pattern (Clarke and Gorley 2006). Numerical environmental data containing information on latitude, longitude, depth, visibility, current flow, temperature, salinity, dissolved oxygen, wind speed, and cloud cover was normalized within PRIMER as a measure of dissimilarity. The objective of this test was to analyze the biotic data and how the environmental data related to community composition. The BEST analysis assumes there is no link between biota and the environment. The BEST analysis using Spearman rank correlation and Euclidean distance resemblance measure produced a rho of 0.187 and a significance level of 0.012 (Table 11). The correlation of longitude, depth, temperature, salinity, and dissolved oxygen is also 0.187 which means

there is a significant link between biota and these environmental parameters. Biotic data also was evaluated over north and south habitats separately. Longitude, depth, temperature, dissolved oxygen, and wind speed were significant factors affecting assemblage data on the north side of South Bimini (p-value = 0.003). On the south side, assemblage data was significantly influenced by longitude, depth, and salinity (p-value = 0.011).

Parameters		
Rank correlation method: Spearman		
Method: BIOENV		
Maximum number of variables: 5		
Resemblance:		
Analysis between: Samples		
Resemblance measure: D1 Euclidean distance		
Variables		
1 latitude		
2 longitude		
3 depth		
4 visibility		
5 current_flow_estimated		
6 temp		
7 salinity		
8 dissolved_oxygen		
9 measured_wind_speed		
10 cloud_cover		
Global Test		
Sample statistic (Rho) : 0.187		
Significance level of sample statistic: 1.2%		
Number of permutations: 999 (Random sample)		
Number of permuted statistics greater than or equal to Rho: 11		
Best results		
No. Vars	Corr.	Selections
5	0.187	2,3,6-8

Table 11. BEST analysis results showing the environmental parameters that affect community composition.

The statistical analysis used to evaluate the environmental parameters described environmental effects on abundance and also determined the best match between the multivariate among-sample patterns of an assemblage and the environmental variables associated with those samples (Clarke and Gorley 2015). The extent to which assemblage and environmental patterns match reflects the degree to which the chosen abiotic data 'explains' the biotic pattern (Clarke and Gorley 2006). Using ANOSIM and BEST

analysis, an association between environmental factors and community composition were analyzed. Numerical environmental data containing information on latitude, longitude, depth, visibility, current flow, temperature, salinity, dissolved oxygen, wind speed, and cloud cover were normalized within PRIMER as a measure of dissimilarity.

A two-way crossed ANOSIM with no replicates was used to compare the reef type (North and South) to the chosen non-numeric environmental factor. A two-way crossed analysis tests for site effect by asking if there is commonality of the among-site pattern across the different environmental factors (Clarke and Gorley 2015). A set number of maximum permutations was chosen (9999) and a plot histogram was created for each comparison. For each ANOSIM, reef had significance, while tide state, current flow, and wind speed did not (p-values: reef = $p<0.05$, tidal state= 0.102, current flow = 0.592, wind direction= 0.388) The comparison of reef (North and South) to habitat type (lagoon and flat) cannot be made because the sampling groups were too small. Reef and habitat type have the same parameters, with North equivalent to 'lagoon' and South equivalent to 'flat' habitat types. There is association between longitude, depth, temperature, salinity, dissolved oxygen, and community composition, but all other parameters are not closely associated with community composition. Reef site and current speed were further compared graphically using an MDS (Figure 8). Comparing current flow and reef in an ANOSIM, there is no separation between levels of the factor (p-value of 0.592). Further, MaxN and current speed were compared using Spearman's correlation test in R Studio. MaxN is not related to the current speed, there is no association between the two variables (p-value = 0.6438).

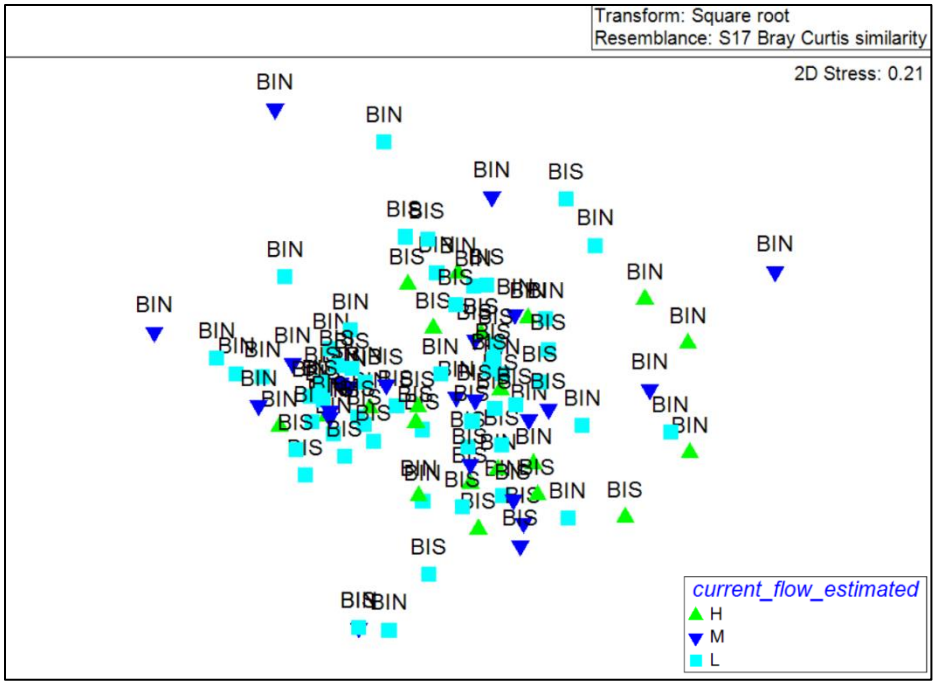

Figure 8. Non-metric multi-dimensional scaling model representing a comparison of reef (North and South) to current flow (high, medium, low) graphically with a 2-d stress level of 0.21.

Environmental factors of reef (BIN or BIS), habitat (lagoon or flat), current flow (high, medium, low), tidal state (ebb and flow), and wind direction (N, NE, NW, S, SE, SW, E, W) were combined with functional group data in order to determine if there was an association between them. Data was square-root transformed. A resemblance matrix with Bray-Curtis similarity was then created from these transformed data. An ANOSIM two-way crossed analysis with replicates (chosen due to replicates within the functional group dataset) was used to compare environmental factors and their effect on functional group data.

An MDS of the three functional groups shows a representation of their relationships (Figure 9). Reef was significant when compared to current flow and tidal state, but not significant when compared to wind direction (ANOSIM p-value for reef = 0.035; 0.01; 0.13, respectively). Functional groups were different at each reef but were not influenced by current flow, tidal state, or wind direction (ANOSIM $p>0.05$). There is no association between environmental factors and abundance of functional groups in the two locations.

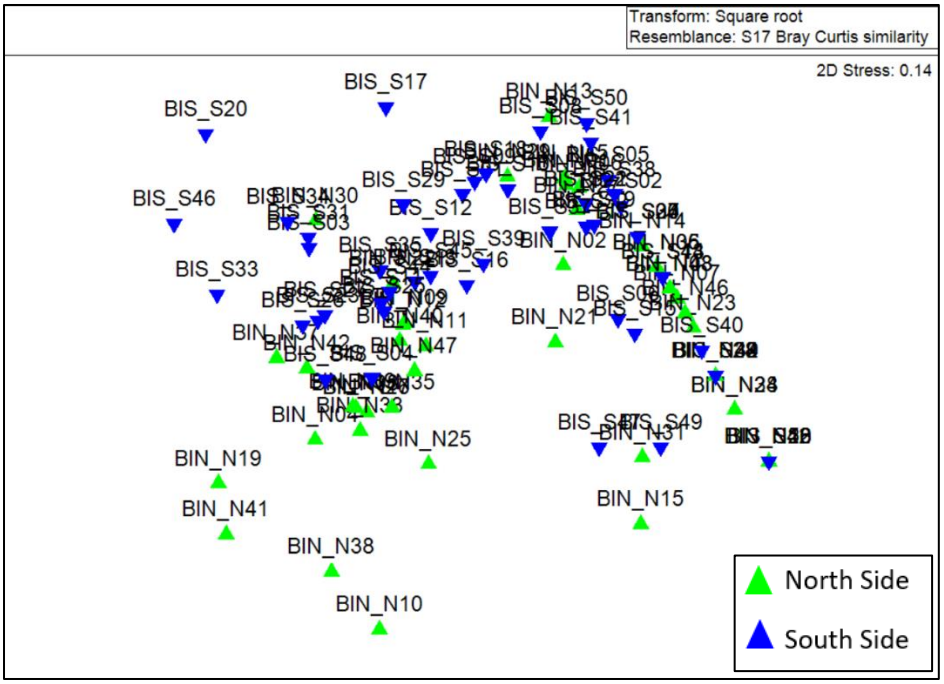

Figure 9. Non-metric multi-dimensional scaling model of functional groups: planktivorous, herbivorous, and piscivorous fish paired with environmental factors, excluding location BIN_N24.

Discussion

The objective of this study was to establish a general baseline of predator and prey species, assess risk-dependent prey behavior, and evaluate the effect of environmental factors on community composition on the north and south shores of South Bimini using BRUVs, which builds upon a previous study in the region. The use of BRUVs provided a non-invasive and minimally disruptive approach to passively observe predator and prey species around the tropical island of South Bimini. It was hypothesized that prey would exhibit greater vigilance behavior as predator abundance increases along the habitat, to mitigate their risk of direct predation. Environmental factors were also predicted to play a role in the composition of predator and prey species in a habitat.

Individuals in each functional feeding group have developed strategies for acquiring food such as ambush, grazing, filter feeding, and cruising movement methods (Villéger et al. 2017). This study evaluated which functional group has the largest aggregation at each site and what environmental factors may play a role in their abundance.

Abundance and Composition

In areas of high predation risk, it was hypothesized that there would either be a high abundance of predators or low abundance of prey. In areas of low risk of predation, it was predicted there would be high abundance of prey or low abundance of predators. There was a significant difference in prey fish communities observed between high risk and low risk areas, with significantly more teleost species counted at the south site—characterized as high risk—and lower abundance of prey in areas of low risk. There was no significance observed in predator abundance at both sites.

Analysis of species abundance at each site describes the top species contributing to the similarity between sites on the north side and from the south side, based on a percent contribution of 90%. Overall, there were similar community composition between both north and south sites. Common species within each site that contribute highly to its similarity of composition include silversides, slippery dicks, bar jacks, sheepshead porgies, and great barracuda.

The analysis revealed that there was no relationship between abundance of predator and prey. It was previously predicted that in areas of high predation risk, there would either be a high abundance of predators or low abundance of prey.

There were more barracuda sightings on the south side than the north side though, there were more shark sightings on the north side than the south side. Overall, there were 53 predators south compared to 42 predators north of South Bimini. Although the south site was predicted to be more high risk, there was a significantly higher number of individual teleosts counted on south than there were north. There was a higher number of predators counted south compared to the north side, but it was not statistically significant. Bimini is an area of high productivity with dense fringing mangroves (Newman et al. 2007). Based on the habitat map (Figure 2) there are high densities of Thalassia and Halodule along the shores of the south side and large patches of sargassum throughout the south, extending further south from the island. The north side of South Bimini has a high density of Thalassia and Halodule fringed along the shoreline as well but is less dense than on the south side. The north side also contains small patches of sargassum and is composed mostly of medium density of Thalassia and Halodule further from the shore. The high abundance of species on the south could be due to the higher density of seagrass

and sargassum covering larger areas of the study site than on the north side. There were inlets in the mangroves on the north side of South Bimini compared to the south side which was characterized by a stretch of mangroves along the shoreline. This organization of the shoreline could contribute to certain predators and teleost's favoring one environment over the other.

Risk Behavior

Predators can influence prey through direct affects or through the cost of anti-predatory behavioral responses or risk effects (Guttridge et al. 2012). The risk of being preyed upon changes through time and space, which makes predator-prey interactions more dynamic. Furthermore, defense strategies have the ability to influence species fitness, community structure, and the function of an aquatic ecosystem (Villéger et al. 2017). Wetzel and Liken (1991) provided considerations for evaluating prey response which included the behavior and energy expended for a flight response and the means by which prey adapt and coexist with predators. Adaptation and coexistence can be accomplished through differences in size, camouflage, aggregation of prey into larger groups, and evasive movements (Wetzel and Liken 1991). Juvenile sharks and smaller-bodied species, however, are subject to predation risk, usually from larger conspecifics. Larger sharks tend not to engage in anti-predatory behavior as adults (Stump et al. 2017). Teleost fish have a strong correlation between body size and risk behavior and use of shallow waters can be size-dependent (Brose et al. 2006)**.** Body size of an individual also determines how long they use a refuge. Body size and risk of predation has a strong correlation in teleost fish, showing that risk behavior can be size dependent (Guttridge et al. 2012). Laegdsgaard and Johnson (2001) investigated size-specific selection of habitats and determined shelter use, feeding rates, and areas of high food acquisition were related to fish body size.

There was no relationship determined to exist in the categorical variables in the population, they are independent. The response to sharks is independent from the response to barracuda. There is no significance between prey and their behavior by predator guild. Furthermore, prey behavior does not differ in low and high-risk habitats. Even though there were more flight responses from sharks than barracuda, there was no

statistical significance between the responses. Prey did not exhibit statistically significant behavior towards one predator guild.

Direct Observation

Stump et al. (2017) stated that the body size at which a juvenile lemon shark perceives reduced predation risk from a larger shark, including conspecifics, is unknown. In the current experiment, juveniles and subadults were only seen in the same video in one location off the north side of South Bimini. Three juvenile lemon sharks were present until two subadult lemons passed in the back. Two of the three lemon sharks disappeared from the field of view and one stayed by the bait box. There is no evidence that the movement of the two juvenile lemon sharks that left was due to the presence of the larger sharks nearby.

There were more barracudas (16) with a presence of a flight response by prey than there were flight responses to sharks (5). However, in each video that had a flight response, there were multiple flight responses by the same species to a shark. Both predator species exhibited a circling behavior approaching the box multiple times in a period of time. If the predator did not initially make contact with the bait box, it would move closer to it with every passing. Even though there were more videos in which there was a yes (1) response to a flight from barracuda, sharks had a higher number of prey flight responses (27 and 32 responses, respectively). For flight response by video and flight response for individual, there was still no significance between prey and their behaviors by predator-guild.

Silversides are a good discriminating species for both north and south sites. A discriminating species contributes relatively consistently to the distinction for all pairs of sites (Clarke and Gorley 2015). They have a low standard deviation and higher ratio. Species with a low standard deviation contribute something to the difference between the north side and south side but does so inconsistently.

BRUVs do not always pick up every species in the area. As the south deployment site 35 was placed in the water, a subadult lemon shark (*Negaprion brevirostris*) swam by and circled within five feet of the deployment and boat until environmental data intake was completed. After the deployment video was viewed, there was no sign of the lemon

shark that was known to have been there. For future experiments, it could be useful to use 360° technology in order to view teleost and predator species behind and to the side of the deployment.

Environmental Influence

Environmental heterogeneity presents challenges for organisms because an individual's performance and overall fitness may vary under differing environmental conditions. Research by Guttridge et al. (2012) suggests that animals assess abiotic conditions in the environment, such as temperature, salinity, and water depth, in order to make decisions about habitat use. This assessment is supported by Abrahams et al. (2007) that stated dissolved oxygen and temperature are important environmental factors which have a potential influence on predator-prey interactions. Abiotic and biotic factors are both drivers of animal behavioral decisions (Dill and Lima 1990; Guttridge et al. 2012, Villéger et al. 2017). In several locations, worldwide, tidal state is known to affect behavior in a number of shark species (Guttridge et al. 2012). Prey communities, along with juvenile lemon sharks using mangrove systems, are predicted to show distinct movement with the tidal cycle. After analyzing tide with assemblage around South Bimini, tide was not a factor that affected assemblage data in this experiment.

Longitude, depth, temperature, salinity and dissolved are environmental factors linked to prey abundances around South Bimini. When assessing north and south sites individually, longitude, depth, temperature, dissolved oxygen, and wind speed were significant factors that affected assemblage data on the north side of South Bimini. Wind speed has partially been an influence on salinity variation affecting species assemblage in a lagoon environment in Puerto Rico (Bruna et al. 2013). Contrastingly, longitude, depth, and salinity were the most significant factors affecting species assemblage data south of South Bimini.

When assessing the overall abundance data across all current flow, there were differences in the composition between the north side and south side based on species count but current flow, tide, and wind speed did not affect what species were present at both sites. There was a significant association between longitude, depth, temperature, salinity, dissolved oxygen and community composition but all other parameters were not

closely associated with community composition. This association means longitude, depth, temperature, salinity, and dissolved oxygen contributed to the species composition at each site. Temperature and salinity are known abiotic factors that act as drivers of movement in shark and ray species (Schlaff et al. 2014). It is possible that these factors are acting together to elicit and influence in community structure, as abiotic factors rarely act in isolation (Schlaff et al. 2014). Temperature and salinity are well-known to have strong influence on the physiology of shark and teleosts (Schlaff et al 2014). Digestion, reproduction, and growth are important metabolic and physiological functions that are determined by their core body temperature which is directly controlled by the temperature of the surrounding environment (Schlaff et al. 2014). Since temperature plays a major role in the biological processes of sharks and teleosts, it is probable that they are sensitive to changes in temperature. Salinity potentially has a greater influence on nearshore species of Bimini since species that are closer to shore are exposed to freshwater runoff that leads to higher salinity fluctuations (Schlaff et al 2014). Most sharks are stenohaline (able to tolerate a narrow range of salinity) and may respond to salinity fluctuations through movement in order to avoid or reduce physiological stress or mortality when salinity falls out of the range of tolerance (Schlaff et al. 2014). It is also possible that teleost species move in order to remain in a range of salinities that are undesirable to predators (Schalff et al. 2014; Simpfendorfer et al. 2011). Smalltooth sawfish (*Pristis pectinata*) are known to occupy salinities (18-24 psu) in estuaries that are outside the range of bull sharks (7-20 psu) (Simpfendorfer et al. 2011). This may be to avoid predation or to reduce energy costs associated with osmoregulation. Dissolved oxygen is known to influence distribution and abundance of several shark and ray species (Schlaff et al. 2014; Coffey and Holland 2015). Bull shark distribution is said to be influenced by optimal dissolved oxygen content (Heithaus et al. 2009; Schlaff et al. 2014). Prey are also able to detect hypoxic stress within predators (Abrahams et al. 2007). Depth has been known to play a key role in movement but is usually associate with other factors such as light availability and tide (Knip et al. 2011; Schlaff et al. 2014). Furthermore, environmental drivers may differ between and within regions for a given species (Schlaff et al. 2014). Distribution of bull sharks in the Caloosahatchee River in Fort Meyers, Florida were influenced by salinity and those in the Florida Everglades were

mostly influenced by dissolved oxygen. Species found north and south of South Bimini may be influenced by environmental factors in different ways and are moving accordingly to the limitations of their ranges of tolerance (Simpfendorfer et al. 2005; Heithaus et al. 2009; Schlaff et al. 2014).

To assess functional groups at North and South sides of South Bimini, each species was categorized as a piscivore, herbivore, or planktivore. Angelfish (*Pomacanthus arcuatus*) in a marine environment are considered omnivorous and mostly feed on sponges. Since angelfish diet also includes jellyfish and small fishes, they are categorized as piscivorous in the functional group dataset. Sharpnose puffers (*Canthigaster rostrate*) are considered omnivorous as well but mostly feed on invertebrates (e.g., worms and shrimps) leading them to also be categorized as carnivorous in the functional group dataset. There was a difference in composition between the north side and south side based on functional groups. Different functional groups are present at different reefs (north vs south) but current flow, tidal state, and wind speed do not affect what functional groups are seen at these reefs. Piscivorous fish were the most abundant functional group north and south of South Bimini, even though there were more individual planktivorous teleosts counted in both sites. This is due to the normalization of the data which evens out abundance values of highly abundant species and rare occurrence species to assess similarities. It is possible that piscivorous fish were more abundant than planktivorous and herbivorous fish because of their attraction to the bait. Piscivorous fish were more targeted during the experiment than were herbivorous and planktivorous fish.

Future Directions- Next Steps

There are still gaps in understanding how predators interact with prey and how significant their affect is. In the future, the incorporation of 360° BRUV systems could produce a better representation of species present at each site in Bimini, The Bahamas. Multiple replicates at each site could also allow environmental affects to be tested against each other at a higher level to evaluate changes in environmental parameters over time. The species information from this study will become part of a habitat map of Bimini via satellite, provided by Save Our Seas Foundation, and will support the Global FinPrint

Project. In the future, more robust studies could create a more comprehensive habitat map and a wider scope of predator-prey interactions.

Conclusion

This study has established a baseline of predator and prey species around the island of South Bimini. This current study also examines predator-prey interaction in regards to teleost flight response by predator guild and recognizes the need for more information on species composition and the role that mangroves play in abundance and distribution. Significant environmental factors that affect community composition have identified in this study as well. Potential site-specific differences may explain the environmental drivers of movement observed between north and south of South Bimini. Understanding how species respond to changes in the environment is important as the climate begins to change and take effect on marine systems. Furthermore, this study highlights the importance of the study of sociobiology and behavioral ecology of species in mangrove and seagrass habitat. Species reliance on mangrove systems could be a substantial case for furthering management and conservation efforts, including establishment of increased protection for fauna and habitat in the westernmost district of the Bahamas.

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